Commercial Building Energy Saver: An Energy Retrofit Analysis Toolkit

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1. ABSTRACT

This paper introduces the Commercial Building Energy Saver (CBES), an energy retrofit analysis toolkit, developed by Lawrence Berkeley National Laboratory. The CBES Toolkit evaluates the energy use of a building, identifies and evaluates retrofit measures. The toolkit provides a rich set of features for energy benchmarking and retrofit analysis, as follows: (1) Energy Benchmarking provides an ENERGY STAR score for the building and how it compares with its peer buildings; (2) Load Shape Analysis identifies potential building operation improvements using statistical analysis of the building's 15-minute interval electricity use data; (3) Preliminary Retrofit Analysis searches a pre-simulated database for retrofit measures based on investment criteria; and (4) Detailed Retrofit Analysis performs EnergyPlus simulation to evaluate energy savings of user configurable energy conversation measures considering the actual building characteristics and operation schedules. A case study is provided to demonstrate the use of the toolkit for retrofit analysis of a small office building. The object oriented software architecture of CBES enables its expansion to cover more building types, more climates, and more building technologies.

2. INTRODUCTION

Small commercial buildings in the United States consume 47% of the total primary energy. Reducing their energy use is key to achieving the U.S. government's strategic goal of reducing oil imports and mitigating global climate change. However retrofitting these buildings poses a huge challenge for small and medium business owners (SMBs), as they usually have little time to manage energy use in their buildings, lack of expertise and resources to conduct detailed on-site energy audit. On the other hand, SMBs represent a largely untapped efficiency opportunity for operations, maintenance, behavior, and whole building savings. More than 45% of energy savings can be realized in small and medium commercial buildings from cost effective retrofits (Preservation Green Lab 2013). SMB owners and energy professionals do not have easy access to low cost tools that can be used to identify cost-effective energy efficient retrofits. Not only is there an information gap regarding opportunities for improved energy efficiency, but small business customers face the challenge of time-of-use pricing. The Commercial Building Energy Saver (CBES) is a new energy retrofit toolkit, developed by LBNL, aiming to fill such gap and challenge.

Figure 1 shows the key components of the CBES Toolkit. It provides the energy benchmarking and three levels of retrofit analysis depending on the degree of the input data provided: (1) Benchmarking is provided using the EnergyIQ (LBNL 2015a) and ENERGY STAR Portfolio Manager (EPA 2015); (2) Level 1: Load Shape Analysis is performed to identify potential building operation problems or unexpected changes in energy use patterns by statistical analysis of the building's 15 minute interval electric load. Level 1 usually recommends no- or low-cost operation improvements; (3) Level 2: Preliminary Retrofit Analysis provides a quick look-up table style assessment of retrofit measures and their energy and cost benefits using a database of energy efficiency performance (Lee et al. 2015), which is compiled from results of about 10 million EnergyPlus simulations covering seven prototype buildings, 16 California climate zones, 100 energy conservation measures (ECMs) and their associated cost data; and (4) Level 3: Detailed Retrofit Analysis performs on-demand energy simulation using EnergyPlus to calculate the energy performance of the building with user configurable ECMs and detailed description of the building and its operation characteristics. The CBES Toolkit considers impact of ECMs on indoor environmental quality (IEQ) during the retrofit of a building.

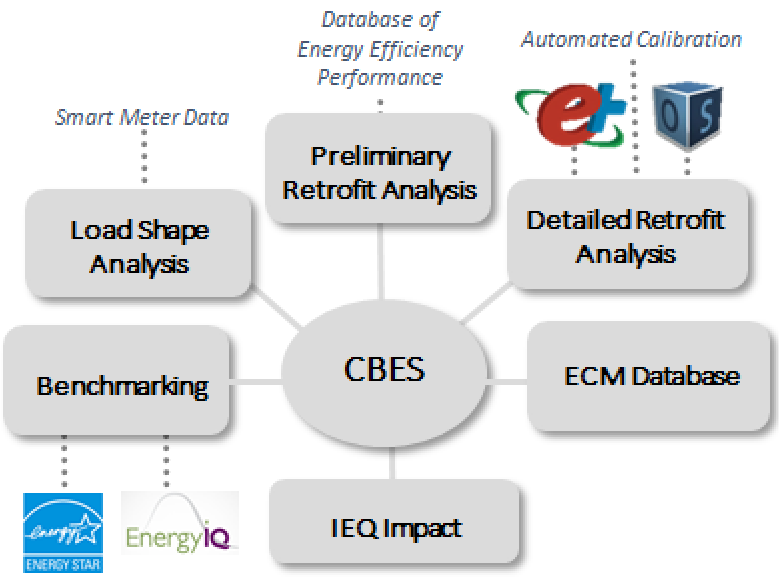

Figure 1. Key components of the CBES Toolkit

3. METHODS

The CBES Toolkit analyzes the energy performance of buildings for pre- and post-retrofit, in conjunction with user's input data, to identify retrofit measures and evaluate their energy savings and economic payback. EnergyPlus (DOE 2015a), the most powerful energy modeling engine, is used to run 10 million simulations on the U.S. Department of Energy's NERSC super computers at LBNL. The simulation results are compiled into a database that provides a quick table lookup searching the top ECMs in terms of energy savings, cost savings, CO_2 reduction, or payback period. EnergyPlus is also used to run the on-demand simulations to provide detailed assessment of ECMs. About 100 ECMs were compiled with performance and cost data from various sources. These ECMs, as individual and in combination, were evaluated, covering technologies of building envelope, lighting, HVAC, domestic water heating, plug-loads, and building operation and maintenance. The ECMs' impact on IEQ is considered during retrofit analysis. The CBES Toolkit builds upon the Application Programming Interface (APIs) of: (1) OpenStudio (NREL, 2015) for managing the creation and execution of EnergyPlus models, (2) ENERGY STAR Portfolio Manager for obtaining the ENERGY STAR score for benchmarking, and (3) EnergyIQ for comparison against peer buildings.

3.1. Software Architecture

Figure 2 shows the schematic diagram of the CBES Toolkit software architecture. The CBES API is the core of the toolkit. It utilizes three external APIs and four databases, including the pre-simulated Database of Energy Efficiency Performance (Lee et al. 2015), the prototype buildings database, the ECMs and cost database, and the zipcode database. A publicly accessible web-based CBES application (CBES App) (LBNL 2015b) is developed to demonstrate the functionality of the CBES API. The software architecture has three layers: (1) the CBES API, the core; (2) the External APIs, the bottom layer, and (3) the top application layer with third party applications/GUIs and CBES Web App.

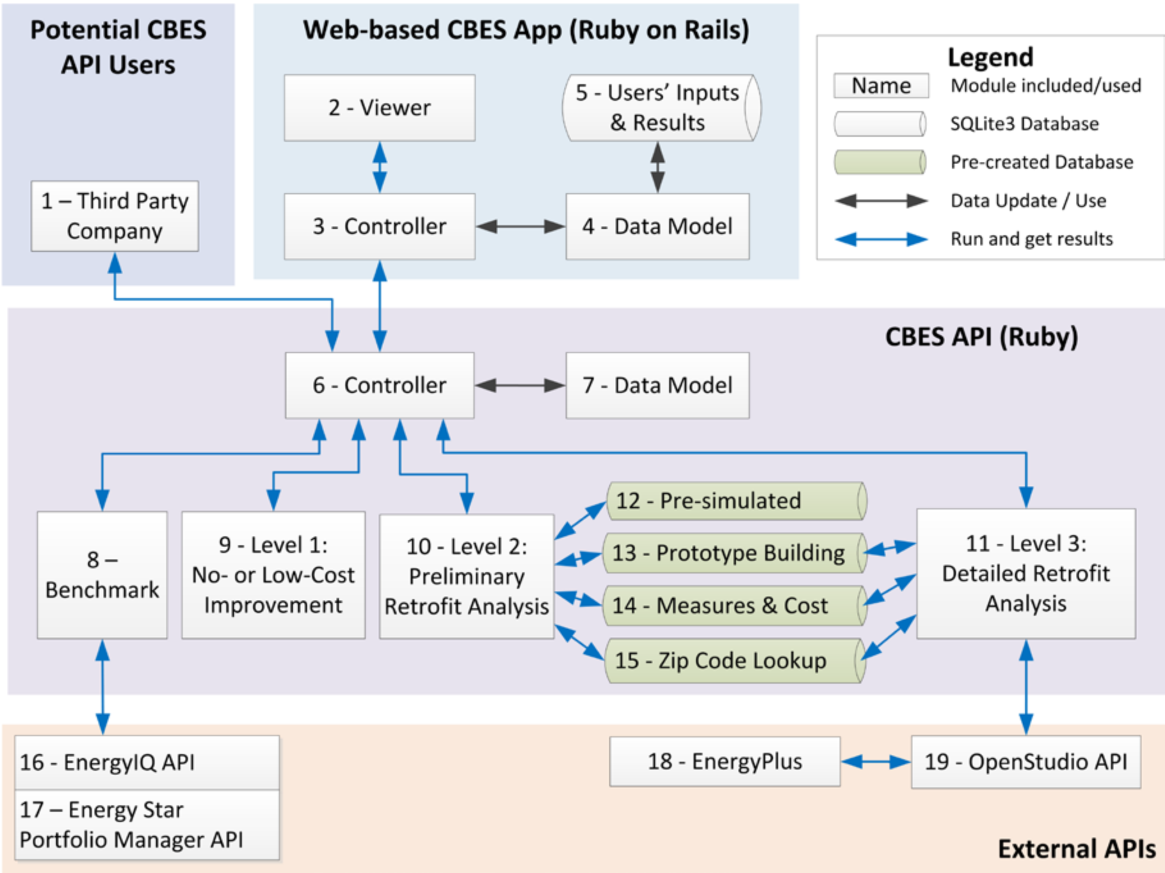

Figure 2. The software architecture of the CBES Toolkit

3.2. Energy Benchmarking

For energy benchmarking, the CBES Toolkit provides a platform to integrate existing benchmarking tools, including EnergyIQ and ENERGY STAR, and it can be extended to include other benchmarking tools, e.g. the Building Performance Database (DOE 2015b). Figure 3 shows an example of benchmarking results from CBES. In this case, the building has an ENERGY STAR score of 38 (a score of 75 or higher qualifies ENERGY STAR certification) and consumes more energy than 80% of peer group buildings. In other words, the building is very poor in energy performance and therefore there is significant energy savings potential in retrofitting this building. The data needed for benchmarking are: (1) building information: type/use, vintage, location and floor area, and (2) 12-month of utility usage data.

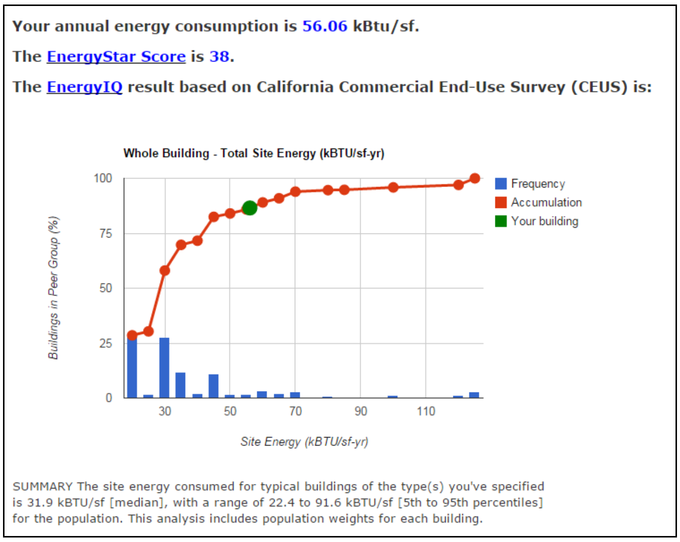

Figure 3. Example benchmarking results from the CBES Toolkit

3.3. Load Shape Analysis – Level 1

The CBES Toolkit provides load shape analysis to identify low- or no- cost improvement opportunities based on statistical analysis of the smart meter data of a building. Figure 4 shows an example of the analysis results from CBES, which calculates the operational and non-operational hours, as well as the average load during those hours. The results indicate that the building has quite high energy consumption during the non-operational hours, which may be caused by leaving the lights and/or equipment on. The results can also include the sensitivity of building energy use vs outdoor air temperature, which indicates a building's overall envelope insulation performance or amount of outdoor air for ventilation or cooling. The data needed for the load shape analysis are: (1) smart meter data, 15-minute interval electricity use, (2) building floor area, and (3) outdoor air temperature, optional.

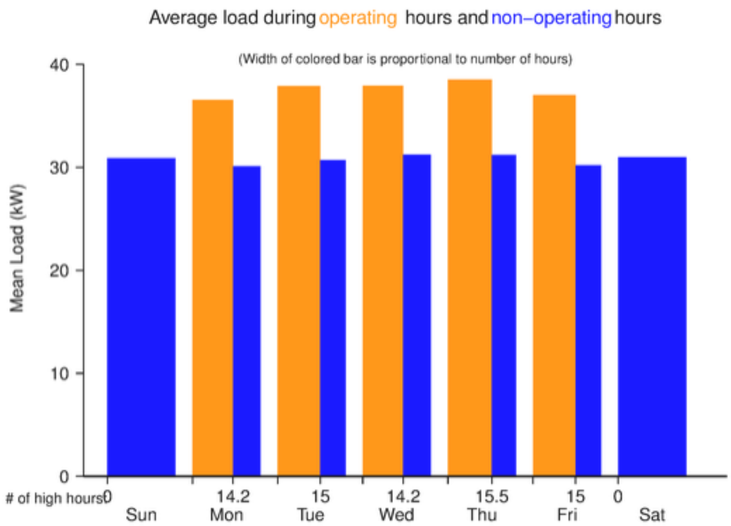

Figure 4. The example load shape analysis results from the CBES Toolkit

3.4. Energy Conversation Measures

The CBES Toolkit includes a rich set of ECMs to be considered as potential retrofit measures. The ECMs database has detailed descriptions of the technical specification, modelling methods and investment cost for each ECM. The measures data are compiled from various sources and cover typical and emerging building technologies of the building envelope, HVAC, indoor lighting, plug-loads, service water heating, outdoor lighting, and building operation and maintenance. A sample list of ECMs is shown in Table 1.

Table 1. A sample list of energy conservation measures in the CBES Toolkit

Category	Component	Name	Description
Lighting	Interior Lighting Equipment Retrofit	Replace existing lighting with LED upgrade (0.6W/sf)	Replace existing lighting to LEDs with 6.5 W/m2 [2.38 Btu/h/ft2]. LEDs consume less power and last longer than fluorescent lamps. A retrofit kit is recommended for converting ballasts. Replacement may improve lighting quality.
Plug Loads	Equipment Control	Use Plug Load Controller (30% efficient from Baseline)	Connect plug loads to a smart plug strip with some or all of the following functions: Occupancy sensing, load sensing, timers, remote control.
Envelope - Exterior Wall	Exterior Wall	Apply Wall Insulation (R21)	Apply blown-fiberglass insulation (R21) to wall cavity will help maintain the thermal comfort. Insulation provides resistance to heat flow, taking less energy to heat/cool the space.
Envelope - Roof	Roof	Reroof and Roof with Insulation	Demolish existing roof, install insulation (R24.83) and reroof to reduced unwanted heat gain/loss. This measure is most applicable to older roofs.
Envelope - Window	Window	Replace fixed-window to U-factor (0.25) and SHGC (0.18)	Replace existing window glass and frame with high performance windows by changing the U-factor and SHGC of the window material. The U-factor is a measure of thermal transmittance and SHGC stands for Solar Heat Gain Coefficient, values taken as 0.25 Btu/(h·ft2·°F), SHGC: 0.18. The SHGC and U-factor are 30% below Title 24 values.
Service Hot Water	Storage Tank	Efficiency Upgrade of the Gas Storage Water Heater	Replace the existing service hot water heater with more efficient gas storage unit, with better insulation, heat traps and more efficient burners to increase overall efficiency of (0.93).
HVAC - Cooling	Cooling System	Packaged Rooftop VAV Unit Efficiency Upgrade (SEER 14)	Replace RTU with higher-efficiency unit with reheat, SEER 14. Cooling only; include standard controls, curb, and economizer.
HVAC - Economizer	Ventilation	Add Economizer	Install economizer for existing HVAC system (includes temperature sensors, damper motors, motor controls, and dampers). Typically an economizer is a heat exchanger used for preheating.
Envelope - Infiltration	Infiltration	Add Air Sealing to Seal Leaks	Air sealing can reduce cold drafts and help improve thermal comfort in buildings. Air sealing is a weatherization strategy which will change the air exchange rate and IAQ.

3.5. Preliminary Retrofit Analysis

The Preliminary Retrofit Analysis feature aims to provide a quick assessment and screening of potential ECMs at the early stage of a retrofit project. DEEP (Lee et al. 2015) is a SQL based database with energy performance of 100 ECMs for various building types and climates. It enables the preliminary retrofit analysis. DEEP is created from pre-simulated results of about 10 million EnergyPlus simulations run on clusters in the U.S. Department of Energy’s NERSC super computer center. Running such a large scale of EnergyPlus simulations would take about 40 years on current desktop computers. The minimal data needed for preliminary retrofit analysis are: (1) building information: type/use, floor area, vintage, and location, and (2) investment criteria, e.g. maximizing energy savings, cost savings, CO_2 reduction, or economic payback. The measures identified from the Level 2 preliminary retrofit analysis can feed to the Level 3 detailed analysis, by proving more building data to customize the prototype building to better match the user’s building.

3.6. Details Retrofit Analysis

Detailed building energy models can help identify and quantify the impacts of the most energy and cost effective retrofit measures. The detailed retrofit analysis provides a streamline process to create and run detailed EnergyPlus models based on user’s customized building information. It enables building owners and managers to make retrofit decisions by providing them the quantified energy and cost performance of the retrofit measures. Default values for all the parameters required to create a detailed energy model are provided based on the zipcode, building type and the built year. Those default values are extracted from different versions of energy standards such as California Title 24 and ASHRAE 90.1. An automatic model calibration procedure is developed to bring the predicated energy consumption close to the utility bills of the baseline building before evaluating the ECMs. Based on the detailed calibrated baseline energy model, single retrofit measures as well as user defined packages of measures can then be evaluated to look at their energy savings and economic metric. This level of analysis enables energy professionals to enter many building data to customize the prototype buildings to better match their buildings. Knowledge of building systems and energy modelling are required to use this level of analysis effectively and correctly.

4. RESULTS

This section provides an example of how to use CBES Toolkit for assessing the preliminary retrofit analysis of a small office building. A hypothetical building owner has a one-story small office building located in San Francisco, California. The building owner would like to benchmark the building’s energy consumption, compared with other peer buildings in California and nation-wide. The owner’s objective is to explore different energy retrofit options to reduce the energy cost of his building. Additionally, the building owner had previously upgraded the lighting system in the building to reduce the lighting power from 2.0 to 1.1 W/ft^2 (21.5 to 11.8 W/m^2). Today, he has a total of $15,000 to invest in the retrofit project. His primary goal is to save energy cost and he wants the payback period to be less than three years. He would like to conduct a preliminary retrofit analysis to identify what retrofit options are available. Therefore, he uses the benchmarking and Level 2 Preliminary Retrofit Analysis features of the CBES Toolkit. The input data includes those listed in Table 2 and 12 month electricity and natural gas use.

Table 2. The input parameters for Benchmarking and Preliminary Retrofit Analysis

Input Variable	***Description***
Building type	1-story office building
Zip code	94127
Built year	1977
Gross floor area	7,500 ft^2 (697m^2)
Total investment	$15,000
Payback period	< 3 years
Previous lighting upgrade	from 2.0 to 1.1 W/ft^2 (21.5 to 11.8 W/m^2)

The annual energy use intensity is 236 kWh/m^2. The benchmarking results show an ENERGY STAR score of 12, indicating the need for an energy retrofit. The EnergyIQ benchmarking result shows that the site energy consumed for a typical building, similar to the user’s building is 101 kWh/m^2 [median], with a range of 71 to 289 kWh/m^2 [5th to 95th percentiles]. The results suggest that the energy performance of the building is poor.

With the basic building information, the CBES Toolkit provides the energy retrofit feedback by querying DEEP database and unearthing the recommended ECMs that meet the building owner's investment criteria. The ECMs are ranked based on the investment criteria, as shown in Table 3. The ECM measures selected are ECM 1 (lighting), ECM 12 (HVAC air economizer) and ECM 15 (plug loads). For each ECM, Figure 3 lists the description of the measure, its potential IEQ impact during retrofit, investment cost, energy use and cost, as well as energy use savings and energy cost savings compared with the baseline building before retrofit. The combination of adding an economizer (ECM 12) and reducing the plug loads (ECM 15) results in the maximum energy cost savings. ECM 1 does not show significant lighting energy savings because the lighting system of the building has been upgraded.

Table 3. Results from the CBES Level 2 Preliminary Retrofit Analysis

Description of measures

Measure ID	Category	Name	IEQ Impact	Cost Unit	Total cost per Unit
ECM 1	Lighting	Replace existing lighting with T8 upgrade (0.7W/sf)	Lighting conditions can affect occupant satisfaction and may affect work performance. Lighting upgrades need to provide adequate illumination and accessible control.	$/sf	0.63
ECM 12	HVAC - Economizer	Add Economizer	Adding an economizer will increase outside air ventilation and can improve indoor air quality. In office settings, studies found that more outside air can reduce sick building syndrome (SBS) symptoms and improve work performance. Similar benefits may also apply to retail and mixed-use buildings	$/ton	387
ECM 15	Plug Loads	Use Plug Load Controller (30% efficient from Baseline)	NA	$/sf	0.8

Annual site energy and CO2 emissions

	Measure ID(s)	Electricity (kWh)	Natural Gas (therm)	Electricity Demand Charge ($)	Energy Cost ($)	CO2 Emission (lbs)
0	Baseline	84,876	648	873	15,766	66,232
1	ECM 12;15	67,767	688	750	12,810	54,954
2	ECM 12;1	68,127	691	760	12,883	55,232
3	ECM 1	75,011	695	784	14,068	60,022
4	ECM 12	76,764	640	847	14,369	60,557

Annual economic analysis

	Measure ID(s)	Energy Cost Savings ($)	Energy Savings (kWh)	Electricity Cost Savings ($)	Electricity Savings (kWh)	Natural Gas Cost Savings ($)	Natural Gas Savings (therm)	Investment Cost ($)	Payback (Year)
1	ECM 12;15	2,956	15,923	2,873	17,109	-40	-40	8,697	2.9
2	ECM 12;1	2,882	15,490	2,812	16,749	-43	-43	7,450	2.6
3	ECM 1	1,698	8,472	1,656	9,865	-47	-48	4,740	2.8
4	ECM 12	1,396	8,341	1,362	8,112	8	8	2,612	1.9

Measure ID(s) with (*) means the retrofit option does not meet the investment criteria.

Annual energy and cost saving percentage

	Measure ID(s)	Energy Cost Savings (%)	Energy Savings (%)	Electricity Usage/Cost Savings (%)	Natural Gas Usage/Cost Savings (%)
1	ECM 12;15	18.70%	15.30%	20.20%	-6.20%
2	ECM 12;1	18.30%	14.90%	19.70%	-6.60%
3	ECM 1	10.80%	8.20%	11.60%	-7.30%
4	ECM 12	8.90%	8.00%	9.60%	1.20%

5. DISCUSSION

The CBES Toolkit provides a rich set of features to support a wide range of users to conduct a quick and reliable retrofit assessment of commercial buildings. One main limitation is the use of prototype buildings that may not be able to be customized to exactly match user's buildings. The other is, despite the customizable pre-selected rich set of ECMs, users cannot add new types of ECMs. The CBES API targets adoption of major software vendors, while the CBES App is a prototype to demonstrate the key features of the CBES API. Future developments include adding the incentives and rebates, renewable energy measures, and demand response strategies.

6. CONCLUSIONS

The CBES Toolkit provides APIs and a web app for a quick assessment of energy conservation measures for an energy retrofit project. The CBES web app is easy and powerful to use for various audiences, including building owners, building operators, facility managers, engineers, and energy consultants, depending upon their experience and the available building data. The CBES Toolkit API can be integrated into third party software and utility portals that provide energy retrofit incentives and energy and cost savings evaluations. The CBES Toolkit can help accelerate the energy retrofit of the small and medium commercial buildings where building owners or tenants have limited resource for detailed on-site energy audits, or have insufficient experience for a comprehensive retrofit analysis on their own. The object oriented software architecture of CBES enables its expansion to cover more building types, more climates, and more building technologies.

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